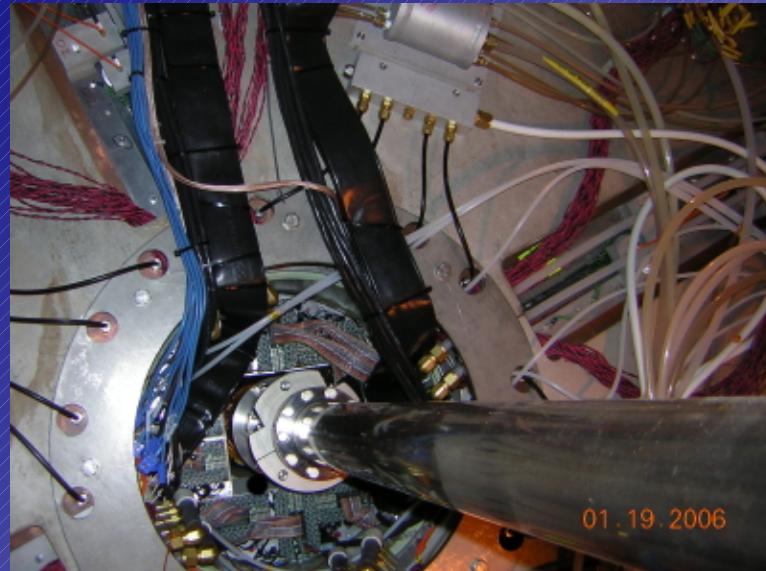




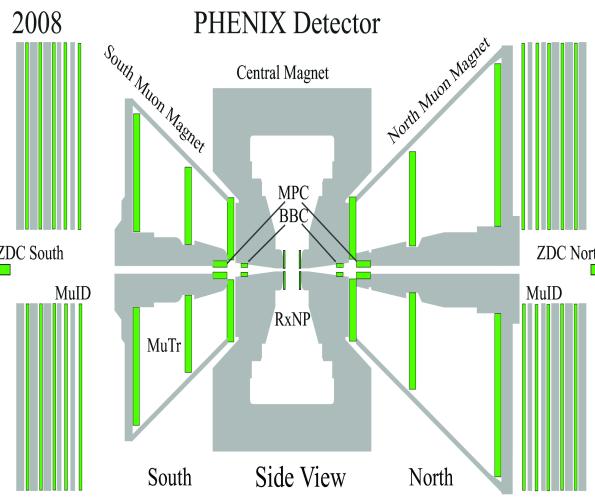
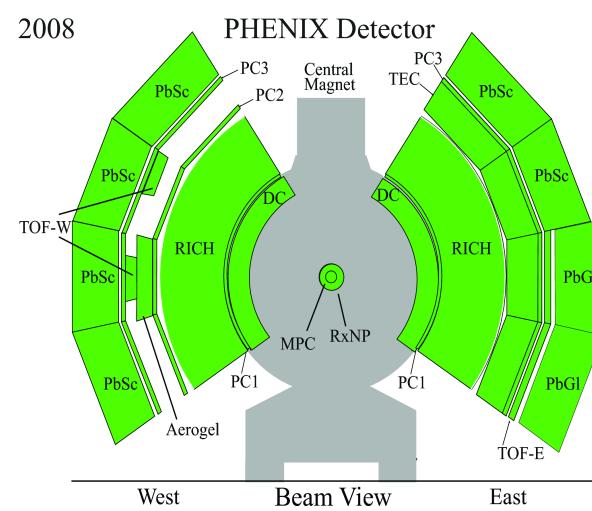
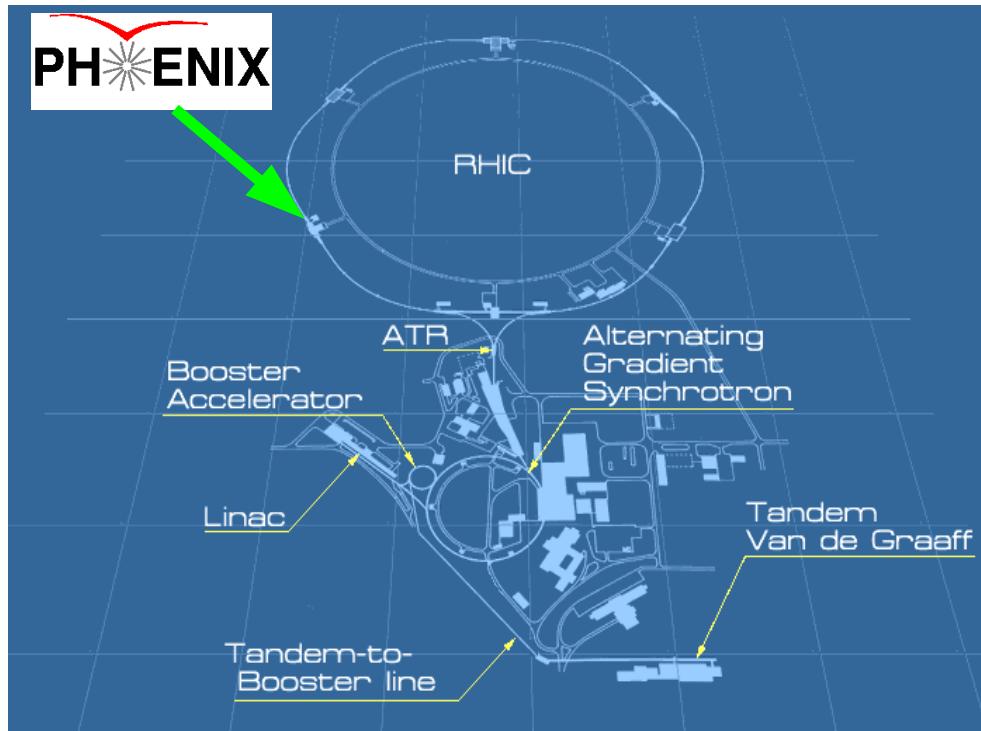
PHENIX Forward Calorimeters



Outline:

- Introduction: The PHENIX Experiment
- Physics Motivation
- Current Calorimetry – MPC
- Future Upgrade – NCC
- Summary

Introduction: The PHENIX Experiment



Central Arm Tracking $|\eta| < 0.35, x_F \sim 0$

- Drift Chamber (DC)
- momentum measurement
- Pad Chambers (PC)
- pattern recognition, 3d space point
- Time Expansion Chamber (TEC)
- additional resolution at high pt

Central Arm Calorimetry

- PbGl and PbSc
- Very Fine Granularity
- Tower $\Delta\phi \times \Delta\eta \sim 0.01 \times 0.01$
- Trigger

Central Arm Particle Id

- RICH- electron/hadron separation
- TOF - $\pi/K/p$ identification

Global Detectors (Luminosity, Trigger)

- BBC $3.0 < |\eta| < 3.9$
- Quartz Cherenkov Radiators
- ZDC/SMD (Local Polarimeter)
Forward Hadron Calorimeter

Forward Calorimetry $3.1 < |\eta| < 3.7$

- MPC- PbWO₄ Crystal

Forward Muon Arms $1.2 < |\eta| < 2.4$

Physics - Motivation

Heavy ions – hot nuclear matter

- R_{AA} in forward direction, esp. π^0 at high momentum
- γ -jet correlations to study opacity of sQGP
- Plasma temperature using charmonium suppression
- Open heavy flavor measurement via electrons (+FVTX)

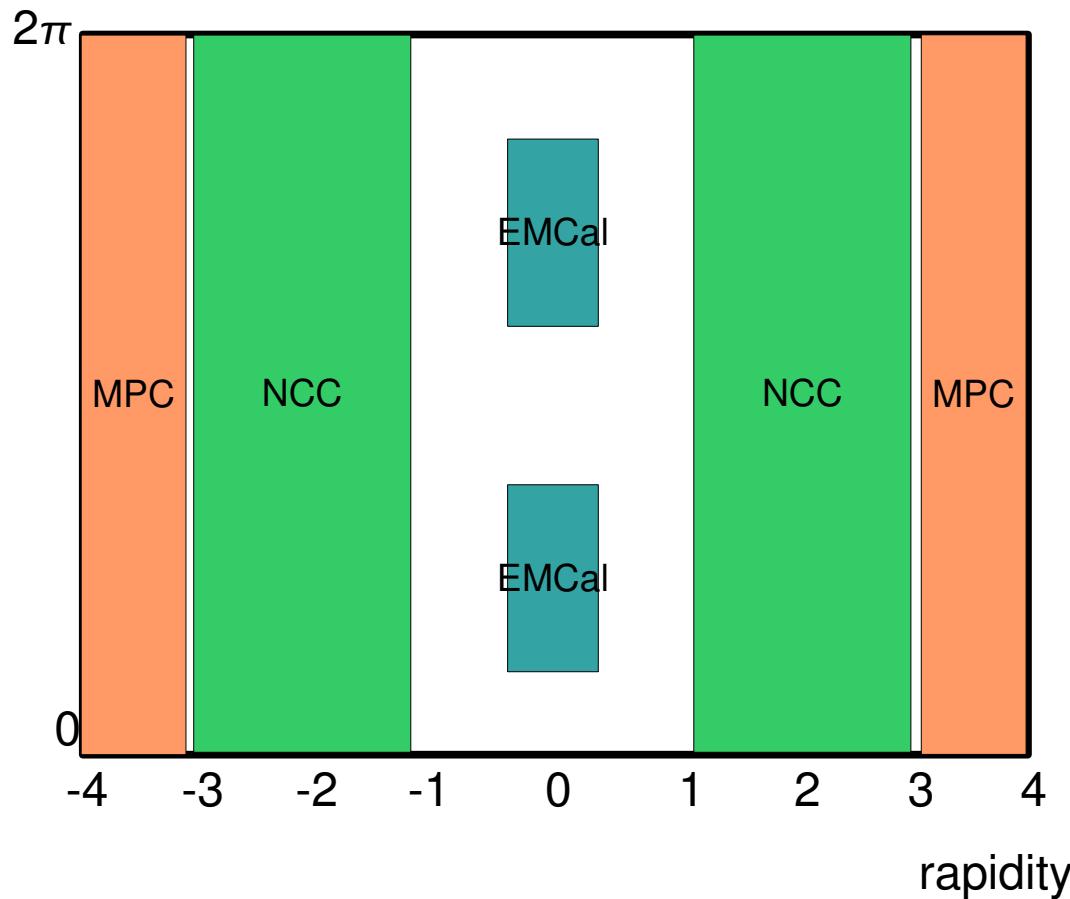
d+Au collisions – cold nuclear matter

- Gluon structure function (saturation at low x ?) by
 - Single hadrons via EM channels ($\pi^0, \eta, \omega, \varphi, J/\psi, \dots$)
 - Direct photons, γ -jet correlations to fix kinematics
 - Dihadron production: π^0 or η in NCC and another in EMC
 - Open heavy flavor production
- Antiquark DF in nucleus at low x via Drell-Yan
- Cronin effect, x_F scaling of produced hadrons in p+A

Polarized p+p interactions – spin structure of nucleon

- Polarized gluon distribution ΔG via single hadrons, direct γ , heavy flavor
- Transverse physics
 - single spin asymmetry A_N – Sivers, Collins, higher twist
 - transversity δg

The PHENIX Acceptance



We have requested funding from the DOE for one NCC. This would give us 3 times more π^0 than the EMCal.

The EMCal only covers a small portion of the phase space, limiting the kind of physics PHENIX is capable of measuring.

The addition of the MPC now expands the acceptance of PHENIX to larger rapidity.

Future upgrades, like the NCC, will open up even more of the phase space to experimentation.

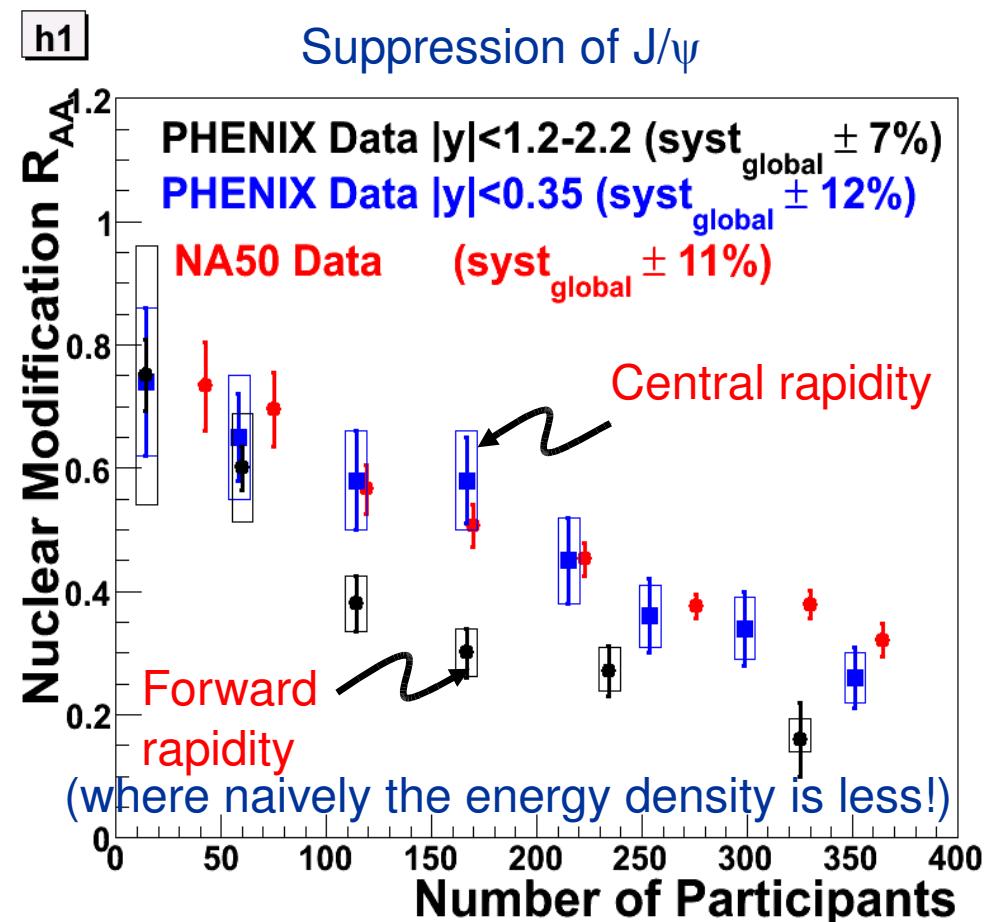
Heavy ions – R_{AA} in forward direction

$$R_{AA} = \frac{dN_{AA}}{\langle N_{coll} \rangle \times dN_{pp}}$$

Suppression is higher in the forward region?!?

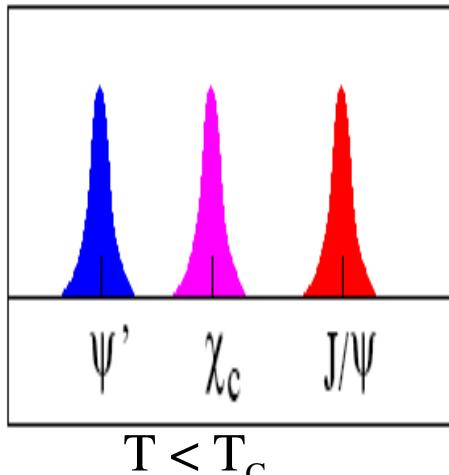
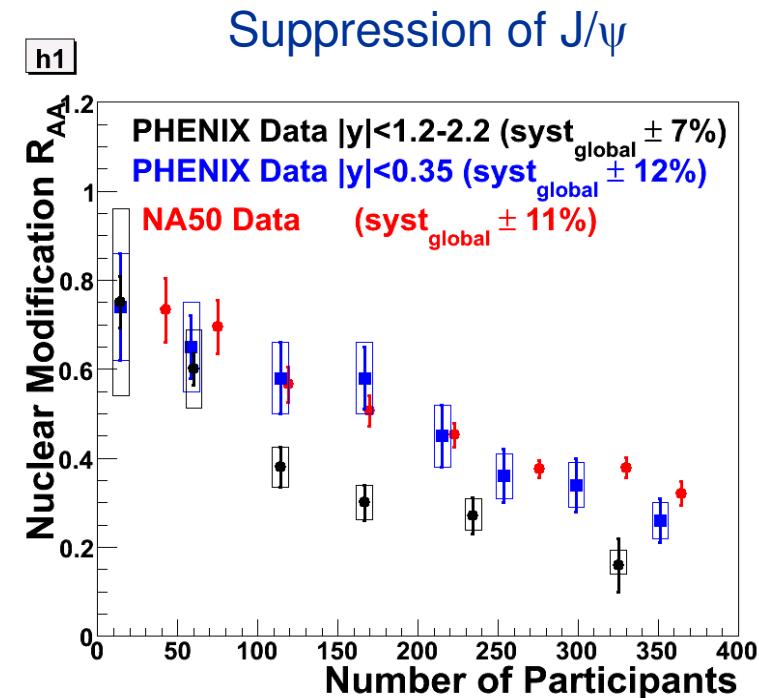
What about other particle species like π^0, η, ω and χ_c ?

NCC will extend the measurement of R_{AA} to 10x large phase space than EMC in central arms.

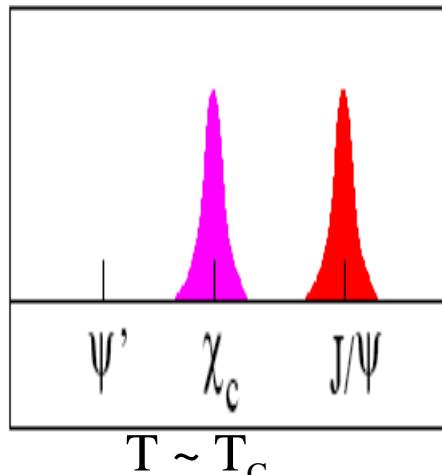


Heavy ions – plasma temperature

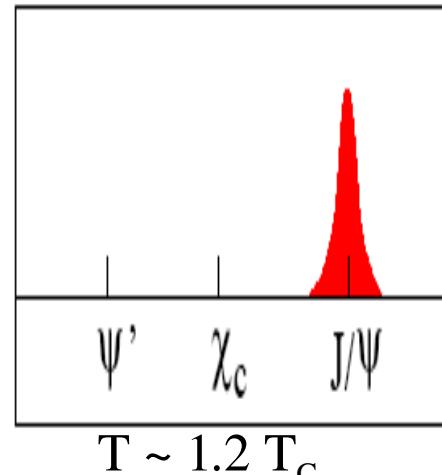
In a hot QCD medium the charmonium states melt sequentially, providing an independent handle on the plasma temperature.



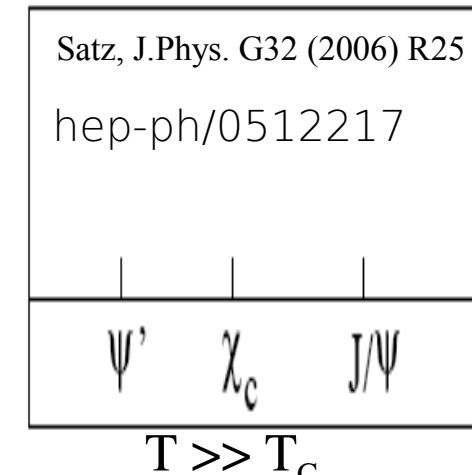
$T \sim T_c$



$T \sim T_c$



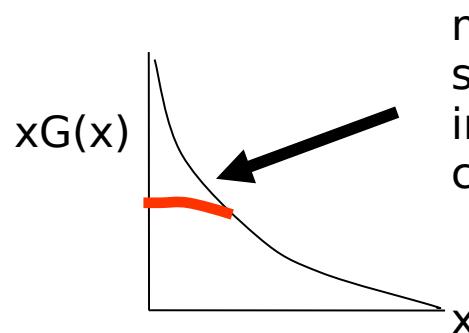
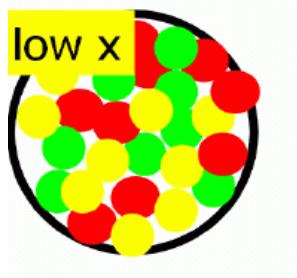
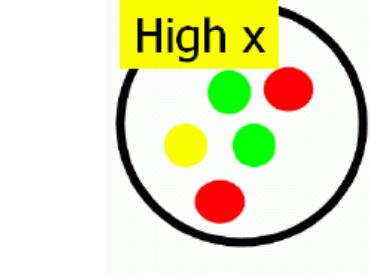
$T \sim 1.2 T_c$



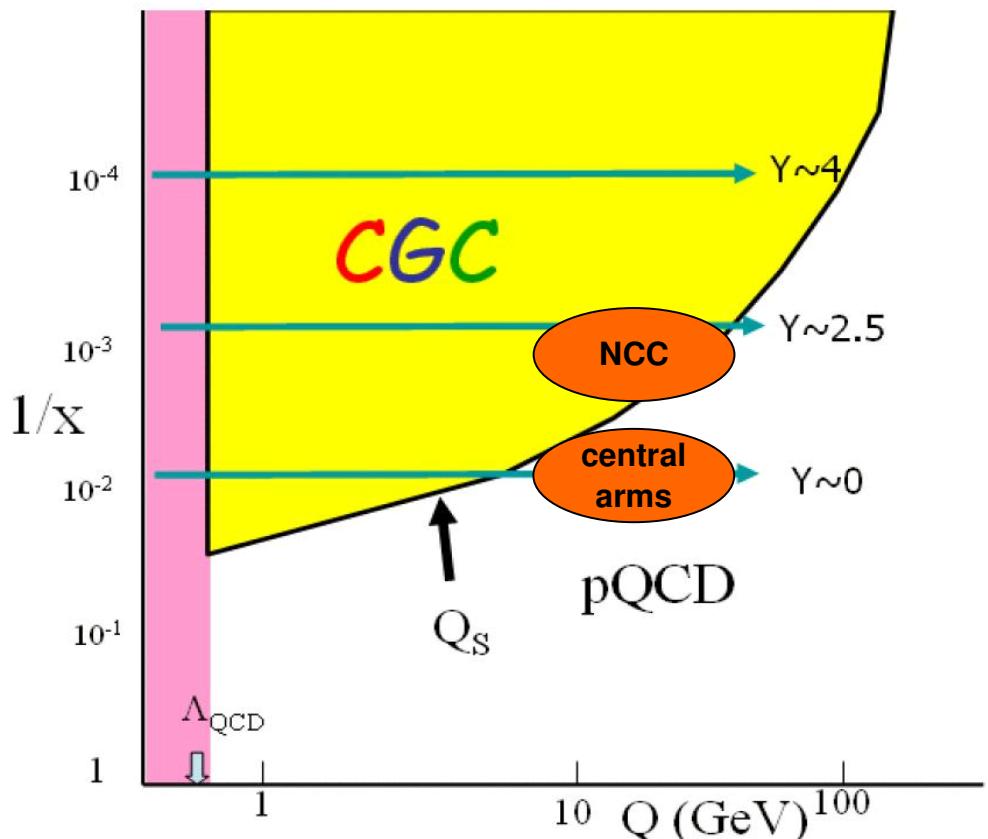
$T \gg T_c$

d+Au – initial state effects

Saturation of gluon density at low x ?

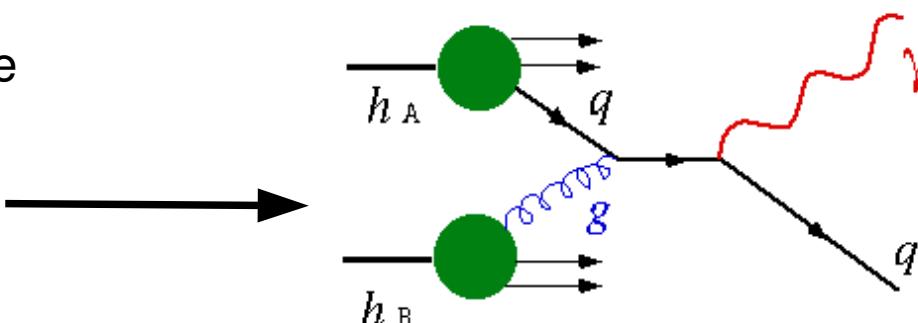


measure gluon
structure function
in forward region
central collisions



NCC (+MPC) provides enough coverage
to exploit CGC region

Best measured by direct photons:



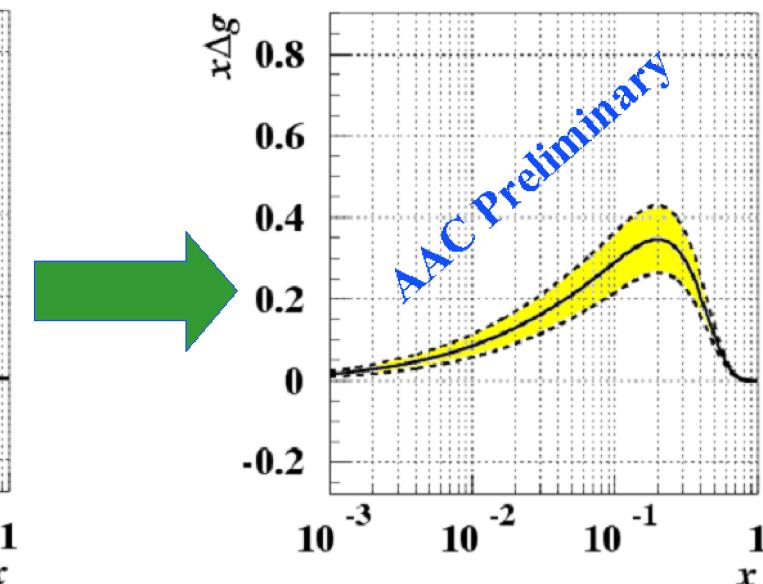
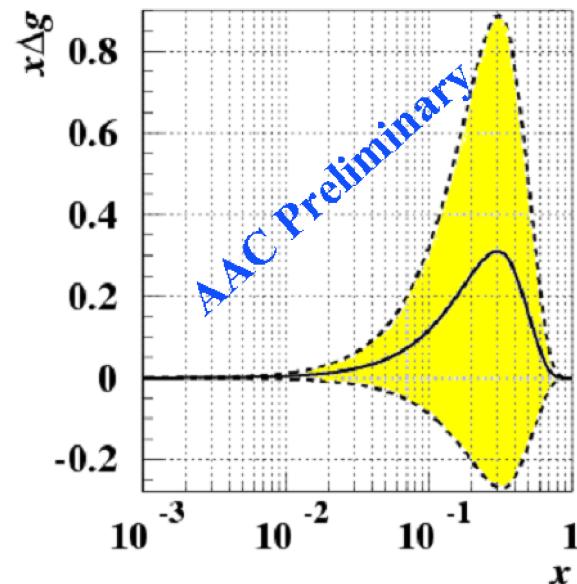
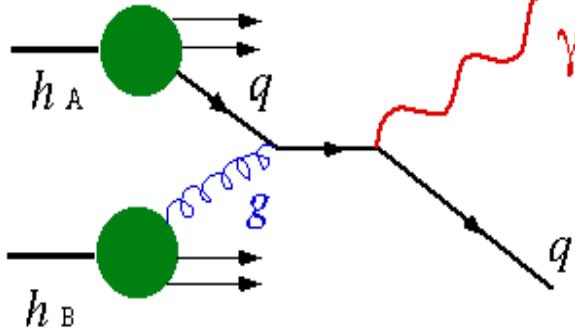
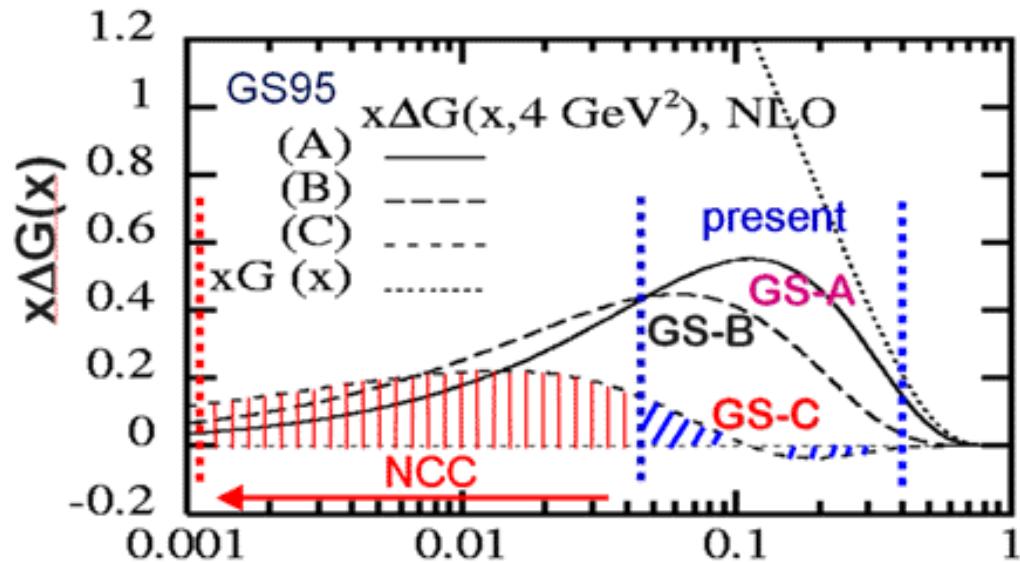
Spin program – gluon polarization

Extending the range of direct photon measurement down to $x = 0.001$ is crucial for gluon polarization measurement.

GS-C consistent with present data

Low x dominated by gluon Compton scattering (85% of cross-section).

Gerhmann-Stirling parameterizations



Transverse Proton Spin Physics

$$\frac{1}{2} = \frac{1}{2} \Delta \Sigma + \Delta G + L_Z^q + L_Z^g$$

$$\begin{aligned}\Delta q &= q_+ - q_- \\ \Delta G &= g_+ - g_- \\ \delta q &= q_\uparrow - q_\downarrow\end{aligned}$$

Polarized parton distribution functions

quark helicity distribution – known

gluon helicity distribution – poorly known

transversity distribution – unknown

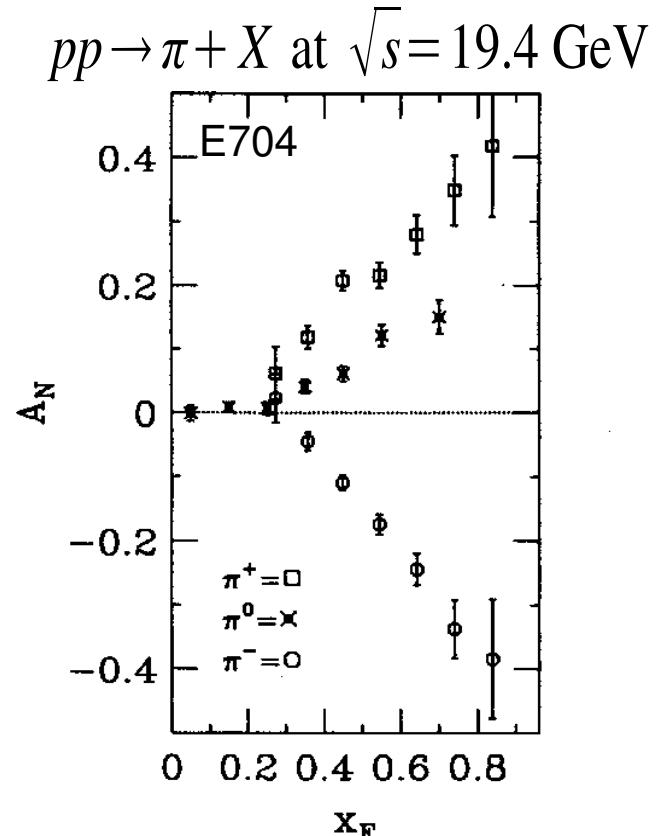
Naïve LO, Leading Twist, pQCD Result

In this note we have pointed out that the asymmetry off a polarized target, and the transverse polarization of a produced quark in $e^+e^- \rightarrow q\bar{q}$, or in $q\bar{q} \rightarrow q\bar{q}$ at large p_T , or in lepton production, should all be calculable perturbatively in QCD. The result is zero for $m_q = 0$ and is numerically small if we calculate m_q/\sqrt{s} corrections for light quarks. We discuss how to test the predictions. At least for the cases when P is small, tests should be available soon in large- p_T production [where currently $P(\Lambda) = 25\%$ for $p_T \approx 2 \text{ GeV}/c$], and e^+e^- reactions. While fragmentation effects could dilute polarizations, they cannot (by parity considerations) induce polarization. Consequently, observation of significant polarizations in the above reactions would contradict either QCD or its applicability.

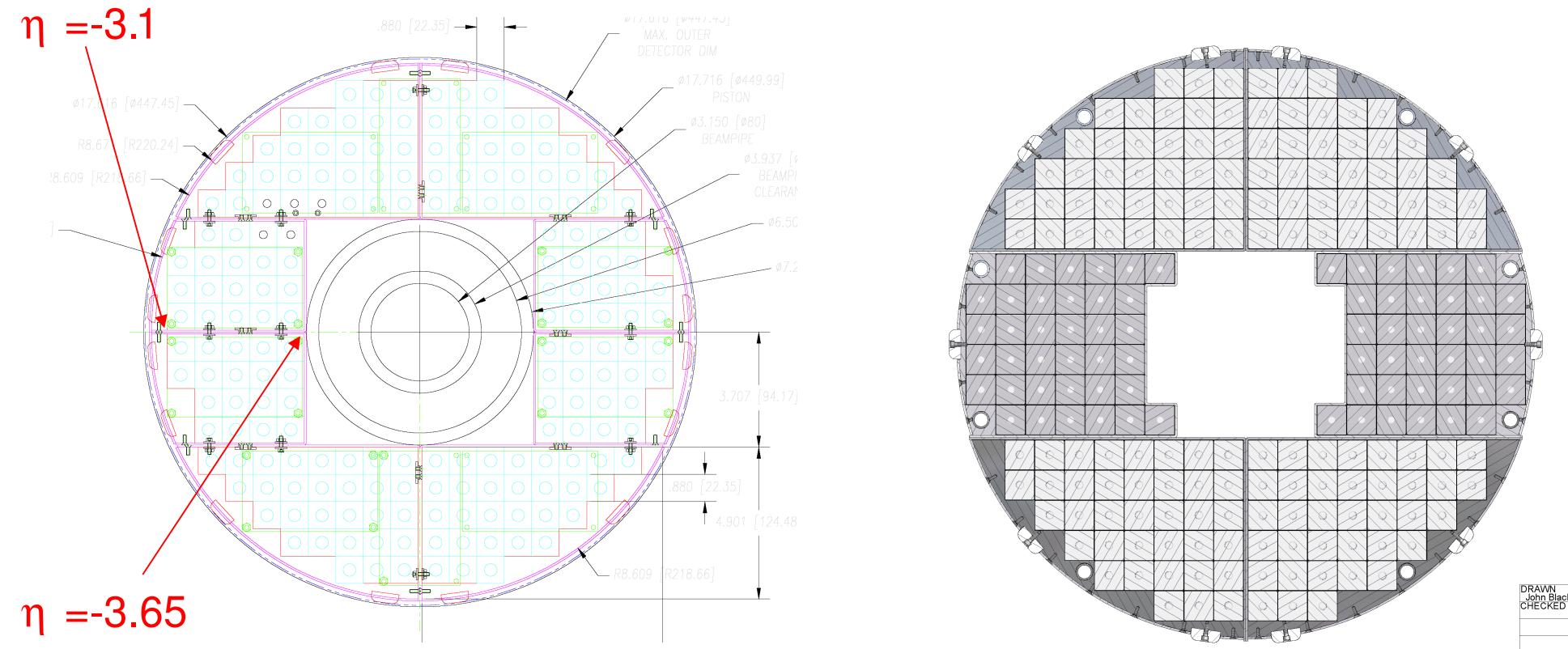
Kane, Pumpkin and Repko PRL 41 1978

$$A_N \propto \frac{m_q}{\sqrt{s}} \quad \text{example, } m_q = 3 \text{ MeV}, \sqrt{s} = 20 \text{ GeV}, A_N \approx 10^{-4}$$

Helicity violation term due to finite quark masses

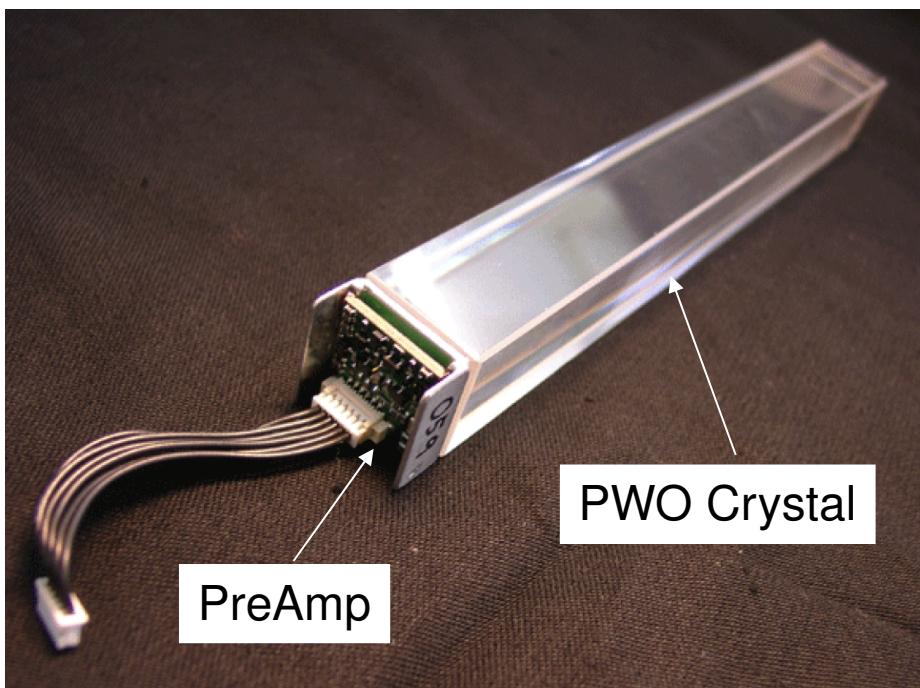


Muon Piston Calorimeter



- South Side: 192 2.2x2.2x18 cm³ PWO crystals arrayed as above, ~220 cm from vertex
 - Will be updated with 4 more crystals in the inner corners
 - Was originally left out due to the .
- North Side: 220 crystals, covering η from 3.1 to 3.9
- Angular Resolution: (Moliere Radius = 2.0 cm)
 $\forall \Delta \eta \times \Delta \phi \sim 0.01 \times 0.01$, comparable to central arms
 - Will have to use same tricks as central arm to id π^0 past ~25 GeV

Crystals and APD Readout



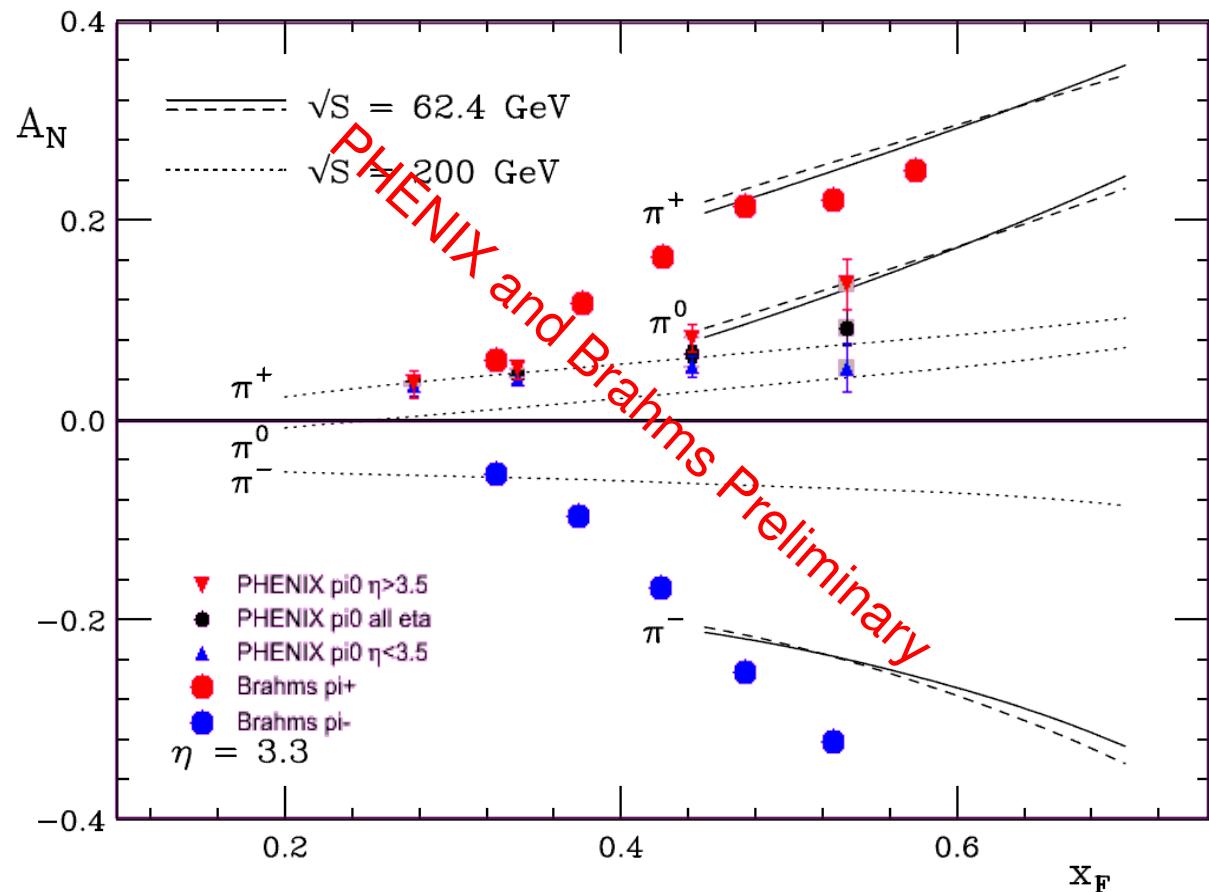
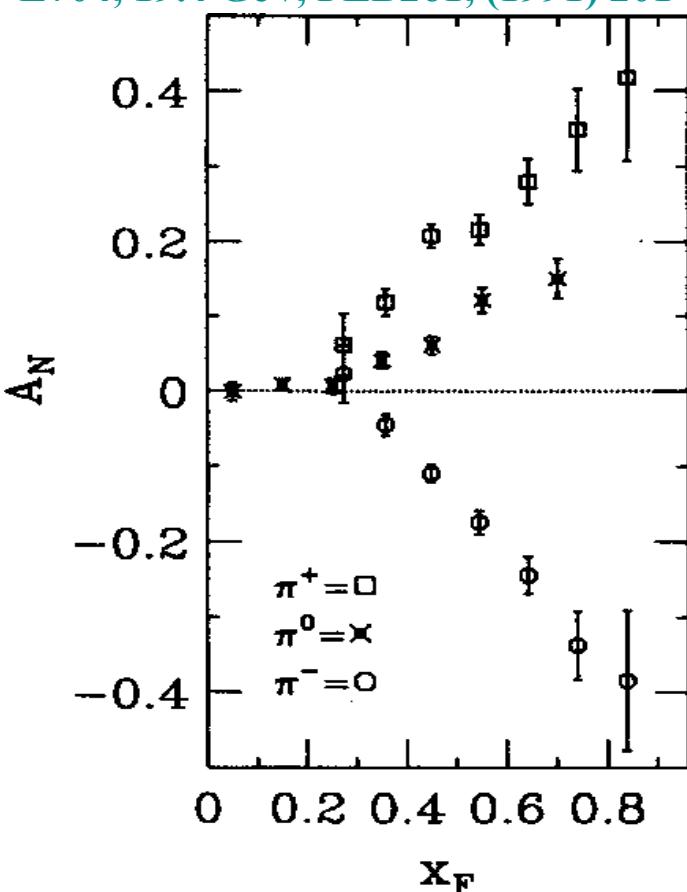
North Crystals PWO (Apatity, Russian)

Density	8.28 g/cm ³
Size	2.2x2.2x18 cm ³
Length	20 X0, 0.92 λ
Weight	721.3 g
Moliere radius	2.0 cm
Radiation Length	0.89 cm
Interaction Length	22.4 cm
Light Yield	~10 p.e./MeV @ 20°C
Temp. Coefficient	-2% / °C
Radiation Hardness	1000 Gy
Main Emission Lines	420-440, 500 nm
Refractive Index	2.16

$$\frac{\Delta E}{E} = \frac{6\%}{\sqrt{E}} \oplus \frac{230 - 330 MeV}{E} \oplus 1\%$$

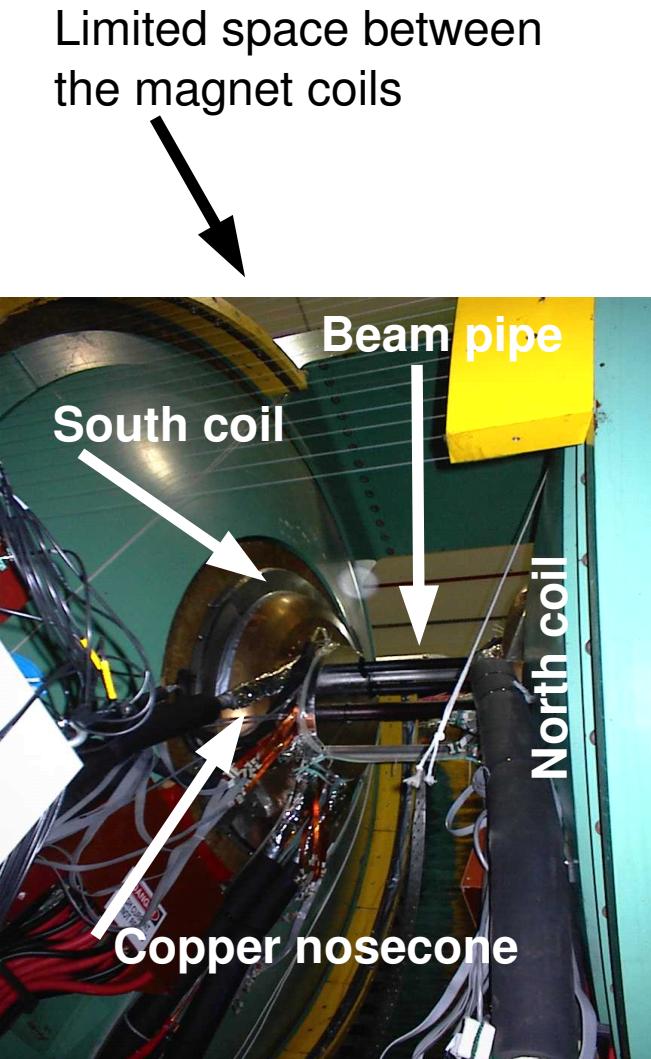
RHIC Forward Pion A_N at 62.4 GeV

E704, 19.4 GeV, PLB261, (1991) 201



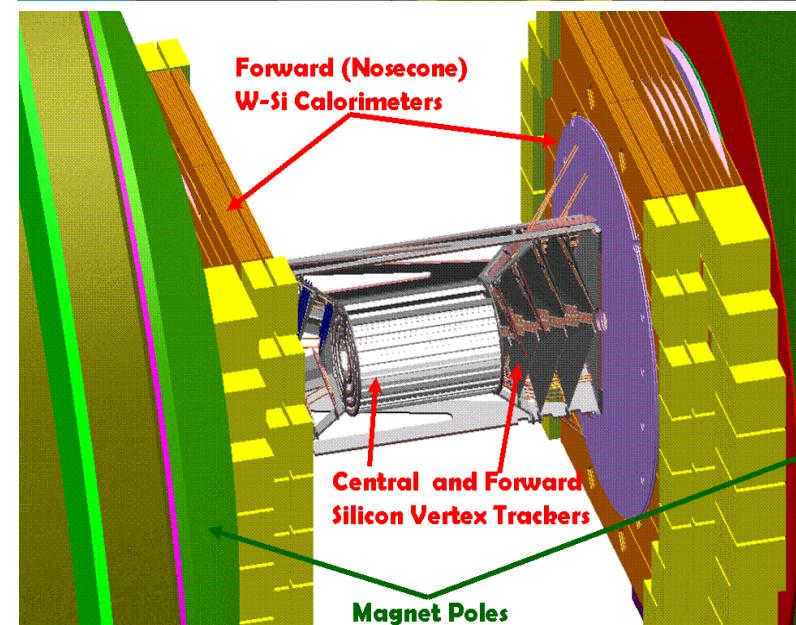
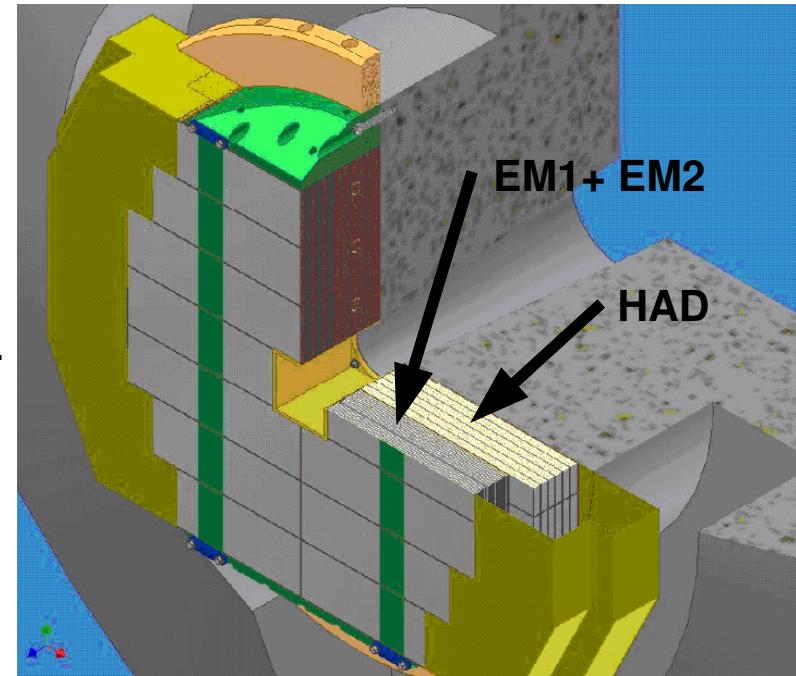
- Brahms Spectrometer at "2.3°" and "3.0°" setting $\rightarrow \langle \eta \rangle = 3.44$, comparable to PHENIX all eta
- Qualitatively similar behavior to E704 data: π^0 is positive and between π^+ and π^- , and roughly similar magnitude: $A_N(\pi^+)/A_N(\pi^0) \sim 25\text{-}50\%$
- Flavor dependence of identified pion asymmetries can help to distinguish between effects
- Kouvaris, Qiu, Vogelsang, Yuan, PRD74:114013, 2006
 - Twist-3 calculation for pions for pion η exactly at 3.3
 - Derived from fits to E704 data at $\sqrt{s}=19.4$ GeV and then extrapolated to 62.4 and 200 GeV
 - Only qualitative agreement at the moment. Must be very careful in comparisons (between expt's and theories) that kinematics are matched, since A_N is a strong function of p_T and x_F .

Future Upgrade: Nose Cone Calorimeter



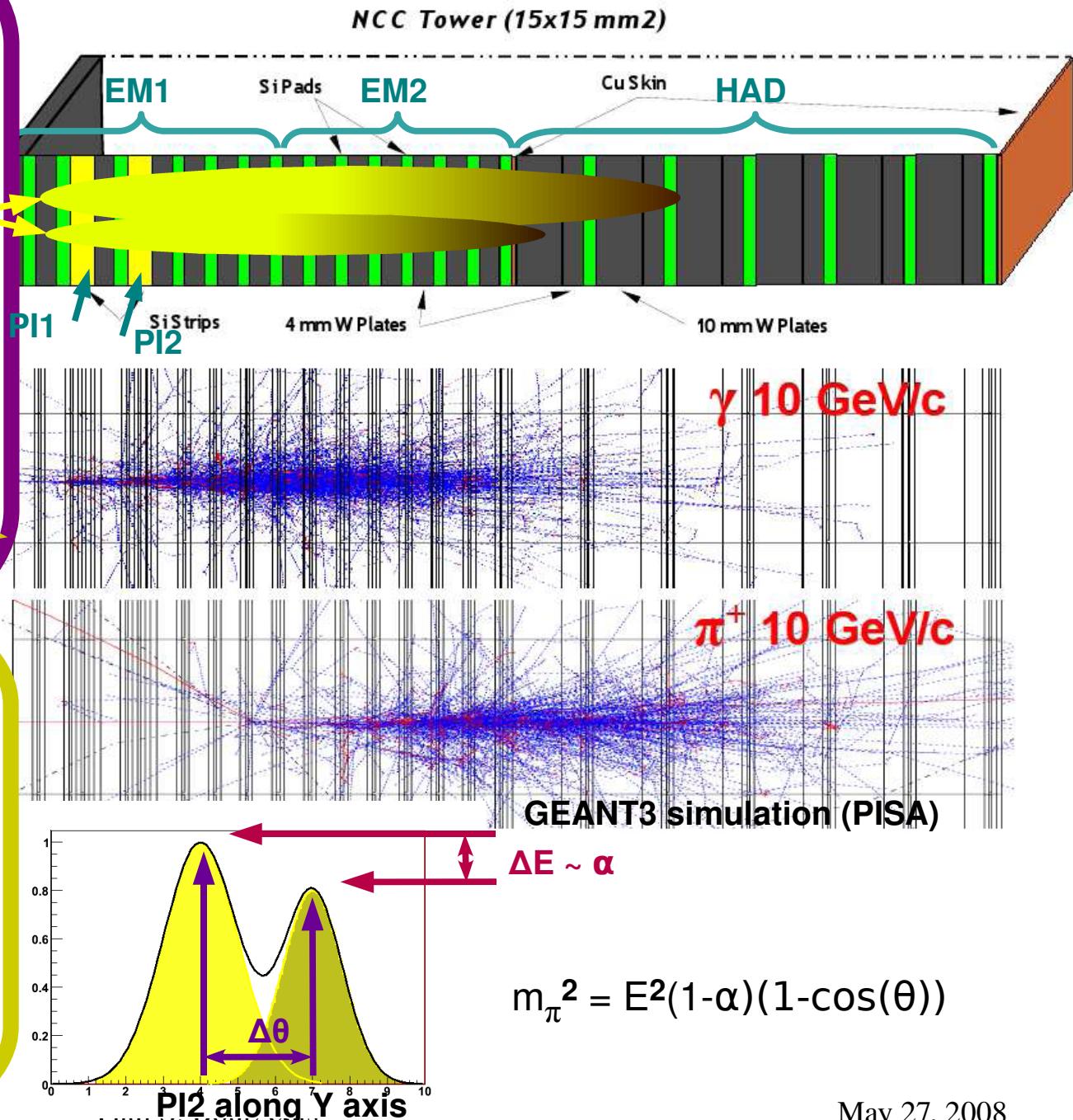
NCC: 19 cm thick W-Si sampling calorimeter with a radius of 50 cm.

- High density: 19.3 g/cm³, small Molière radius: 9mm
- Mounted on the magnet coils.
- Front face 41 cm from nominal vertex.
- 3 longitudinal segments (EM1, EM2, HAD)
- Depth $35 X_0$ ($1.3 L_{int}$): $(8 + 8 + 19 X_0)$
- 2 photon identifiers (PI1, PI2) to resolve single shower π^0 s at $(2, 3) X_0$; shown on the next page

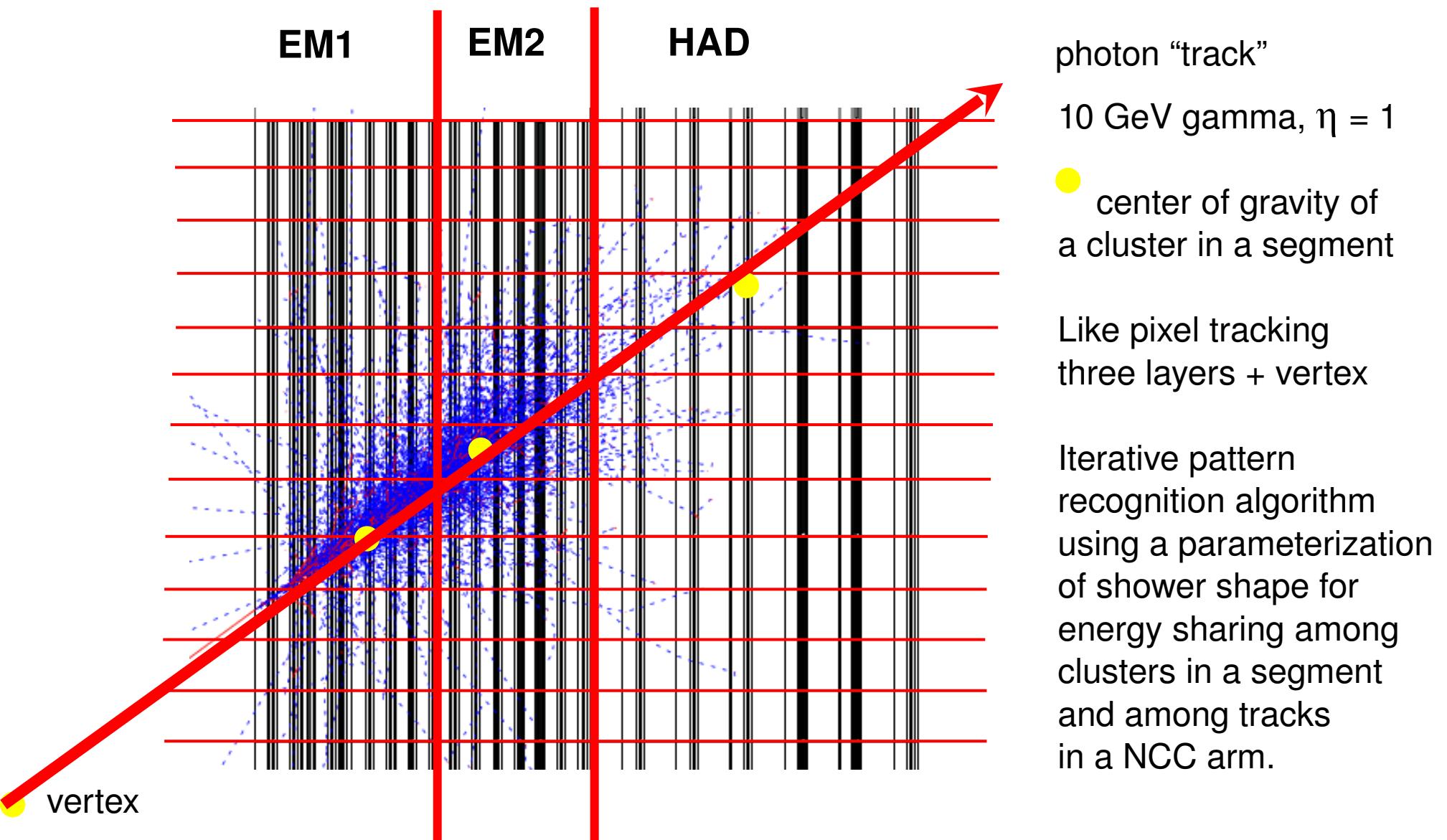


NCC towers

- Detector segmented to towers 15x15 mm²
- Each tower made of EM1, EM2, HAD sub-towers summing signals from Si pads
- Longitudinal segmentation allows for EM shower (e, γ , π^0) identification and hadron rejection thanks to different physics of EM vs. HAD shower.
- Transverse shower profile is less sensitive but useful too.



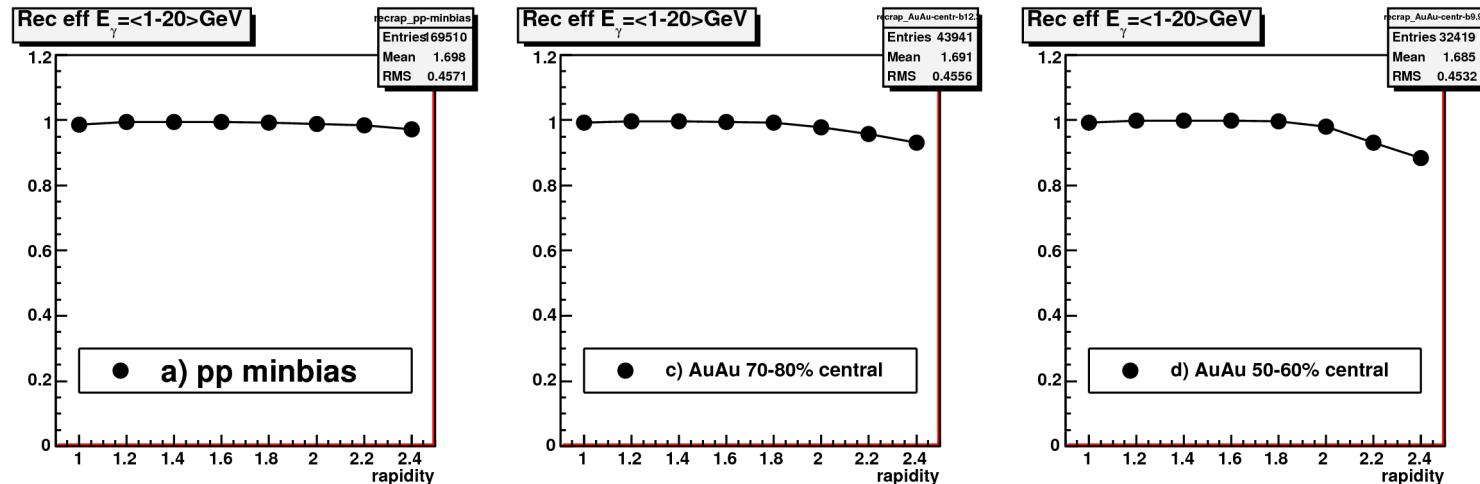
NCC - a tracking calorimeter



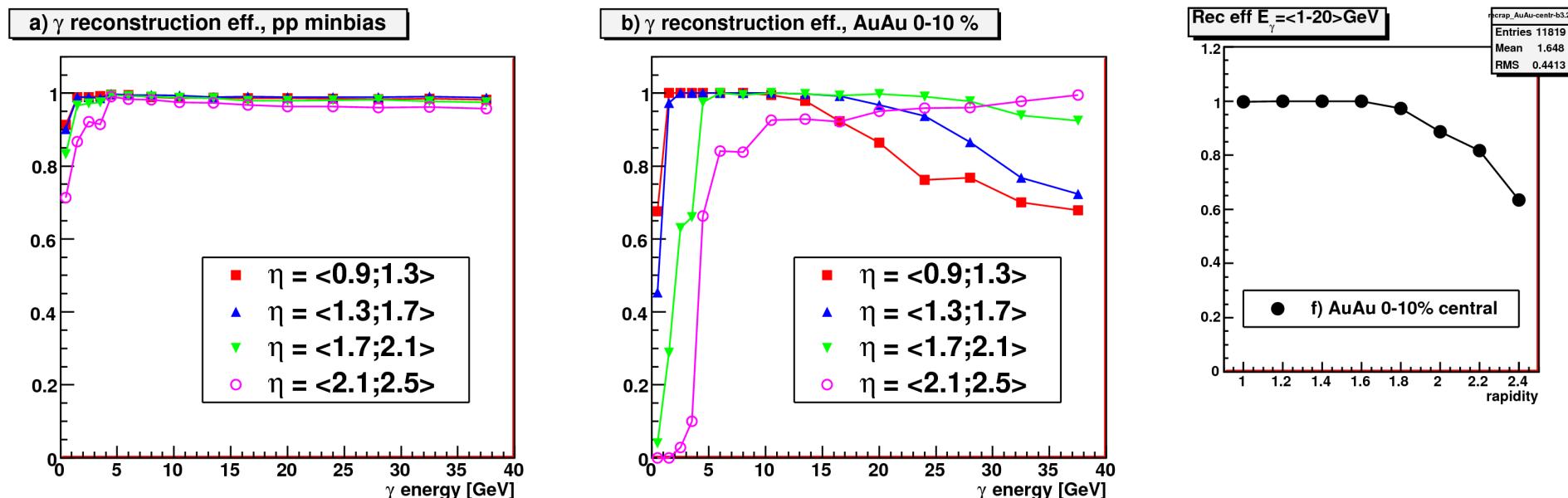
Reconstruction efficiency of γ s

Single photons merged with different types of background events: p+p, d+Au, Au+Au

Reconstruction efficiencies 1) $f(\eta)$ for finding photons with energies 1 – 20 GeV:



2) $f(E_\gamma, \eta)$:

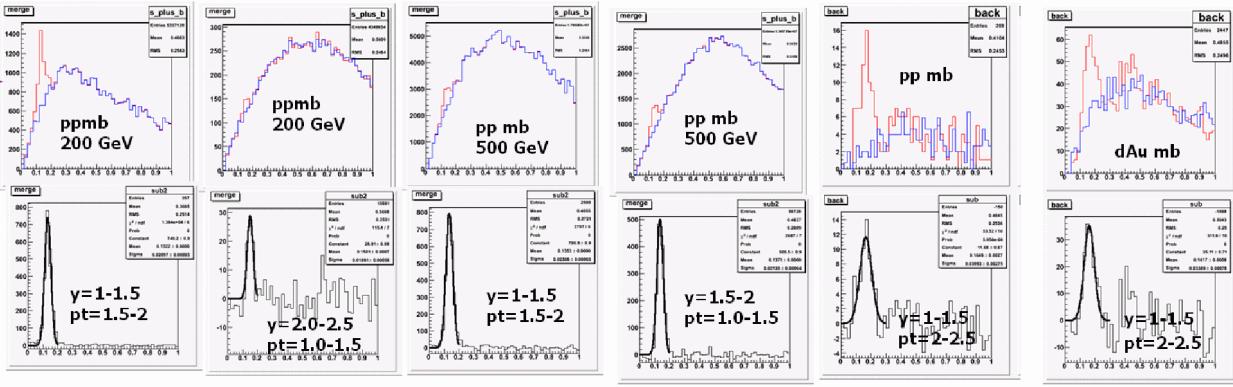


Identification of π^0 s

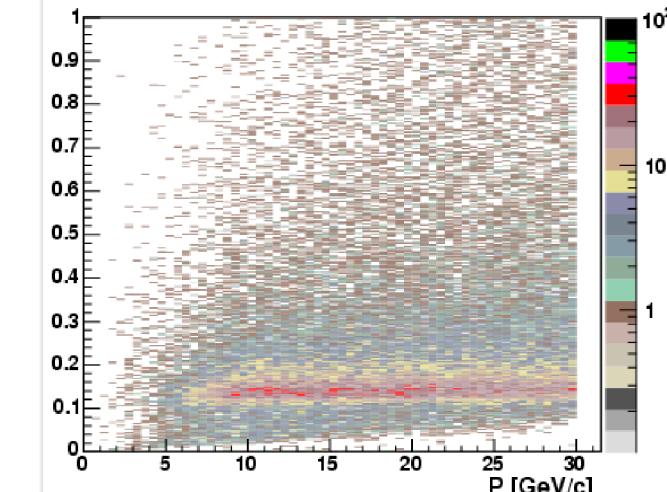
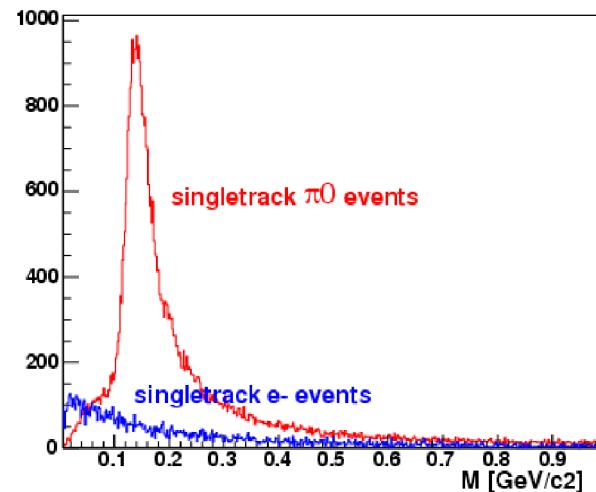
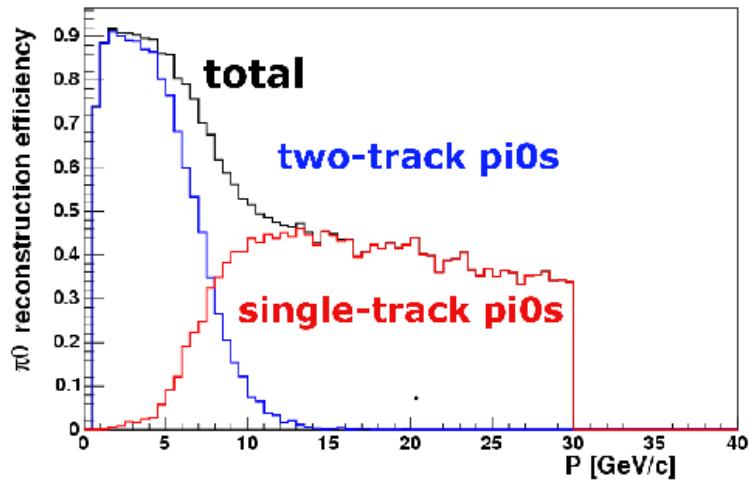
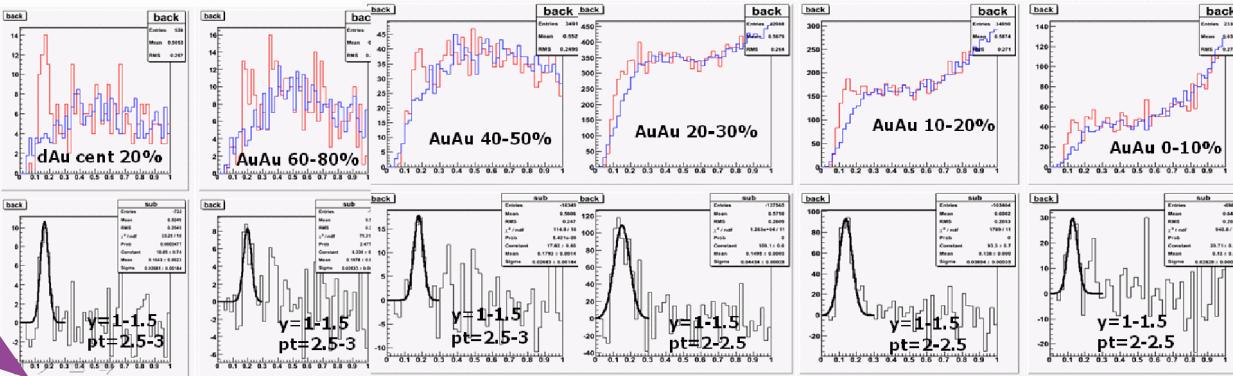
1) Two track method:

Each decay photon is seen as
a separate shower.

Works for $p_{\text{Tot}} < \sim 7 \text{ GeV}$



2) Single track method:
the decay photon showers
merge, invariant mass is
calculated using NCC PI1 and PI2

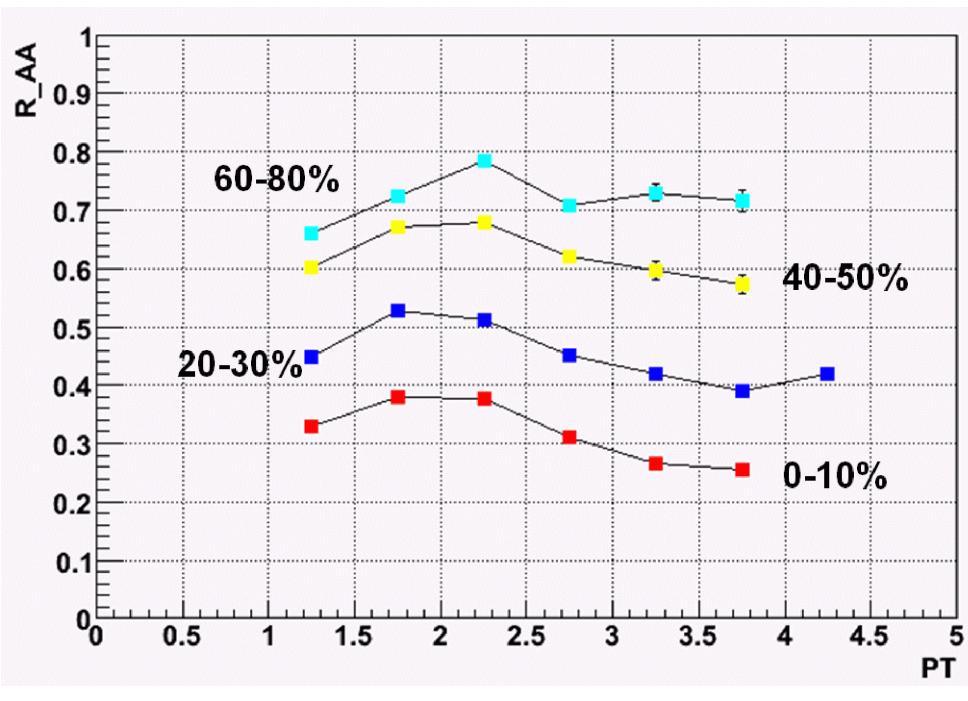


Expected NCC performance

I. $\pi^0 R_{AA}$ in Au+Au

One 12 week run at RHIC II lum.

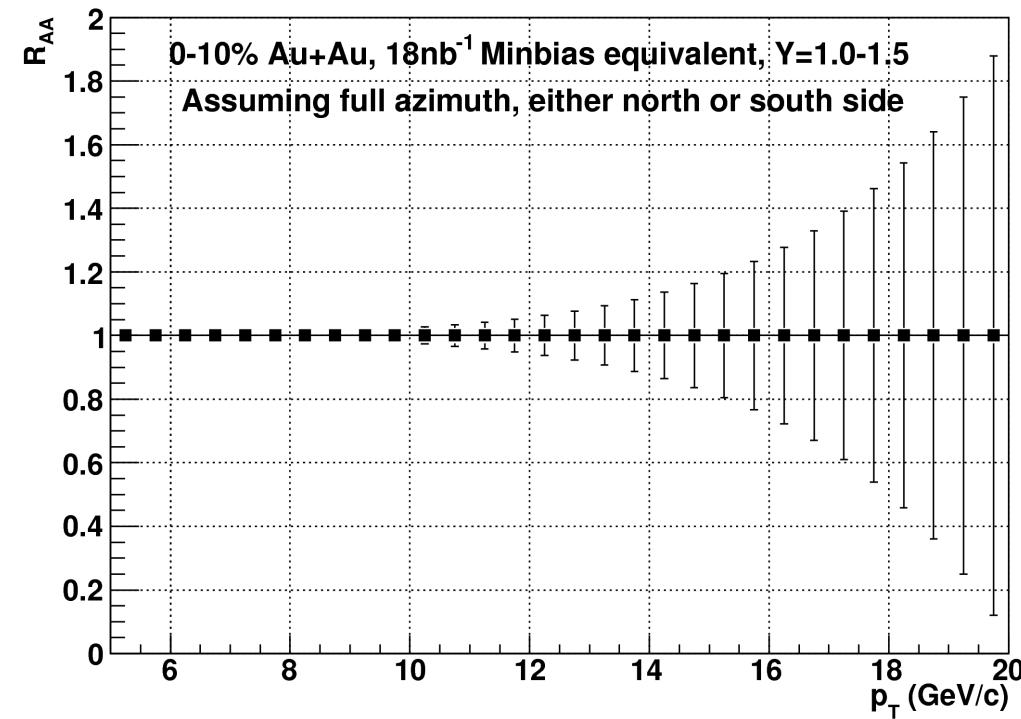
Watch the error bars



Two track method

R_{AA} values taken from central arms measurement

RHIC & AGS Users Meeting



Single track method, Au+Au central 0-10%

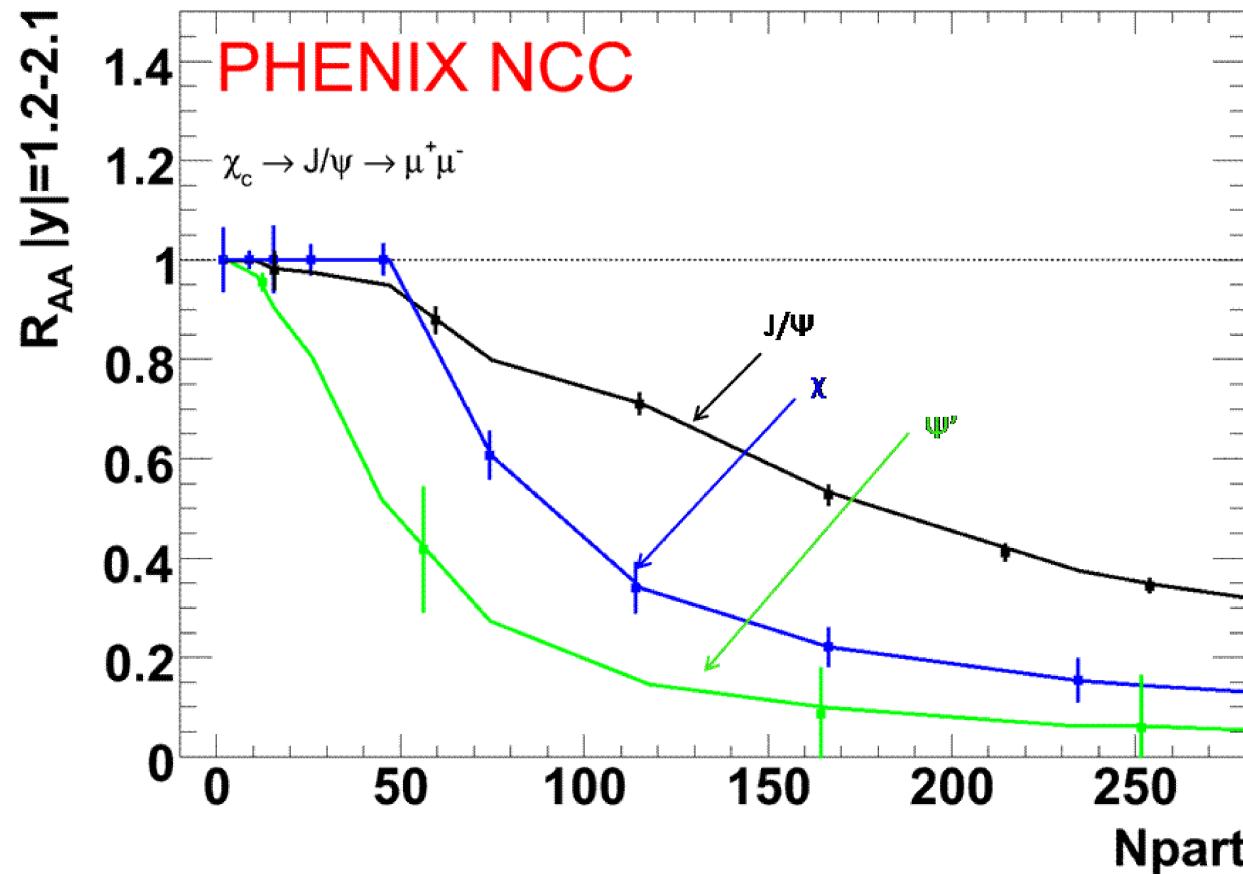
R_{AA} set to one, suppression expected as in the central arms

Paul S. Bourgeois

May 27, 2008

Expected NCC performance

III. χ_c R_{AA} in Au+Au



One run at RHIC II luminosity, watch the error bars

Modeling A_{LL} at Forward Rapidity

A_{LL} expressed in its factorized form

The analyzing power is calculable using pQCD.

$$A_{LL} = \frac{\Delta g(x_g, Q^2)}{g(x_g, Q^2)} \otimes \frac{\Delta q(x_q, Q^2)}{q(x_q, Q^2)} \otimes \hat{a}_{LL}(s, t, u)$$

The polarized distribution functions are calculated using a variety of parameterizations like GS and GRSV.

The unpolarized parton distribution functions are calculated using CERN Libraries.

Modeling A_{LL} at Forward Rapidity

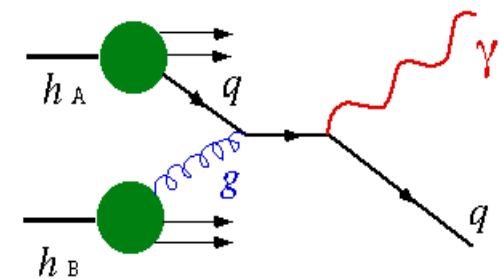
p+p events are generated using PYTHIA

Direct photons are tracked through the NCC using PISA.

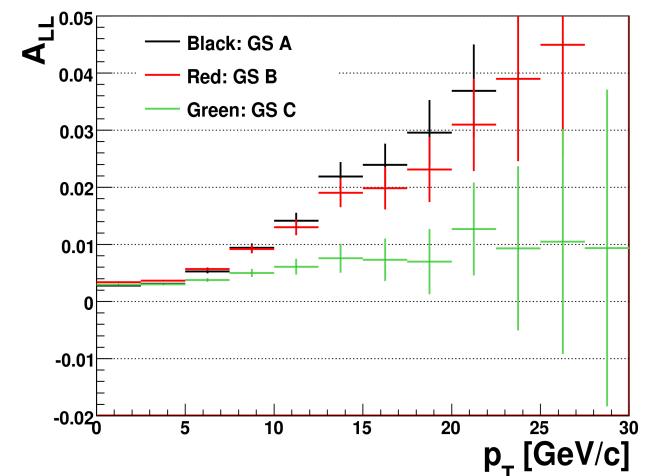
The invariant cross section for reconstructed direct photons is calculated.

A_{LL} is calculated on an event by event basis and direct photon cross section is weighted.

Ratio of weighted/unweighted cross section gives A_{LL} .

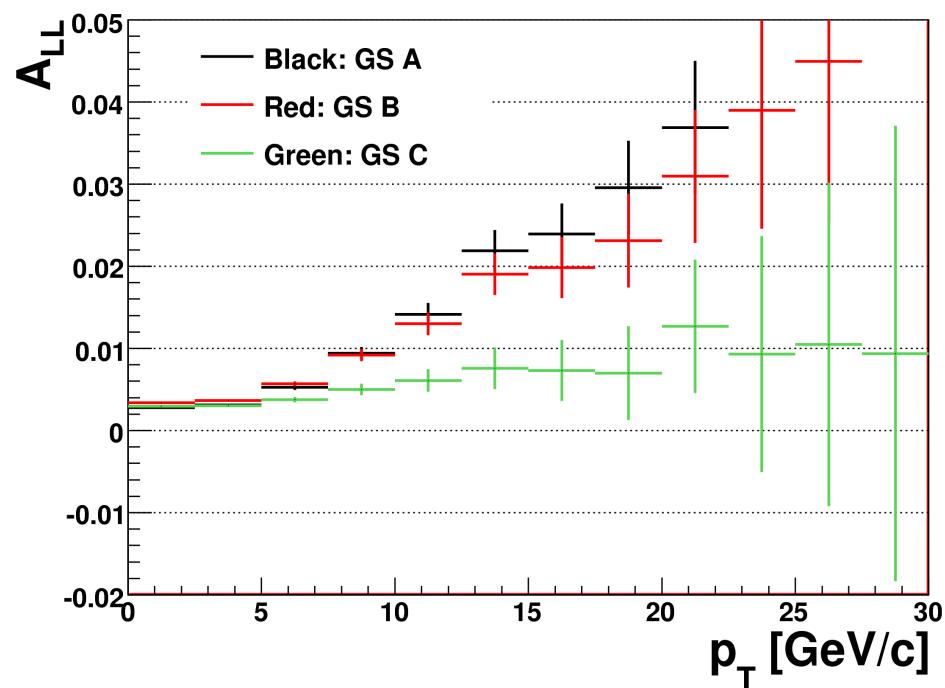


$$E \frac{d^3 \sigma^\gamma}{dp_T^3} = \frac{1}{2\pi p_T L} \frac{d^2 N^\gamma}{dp_T dy}$$



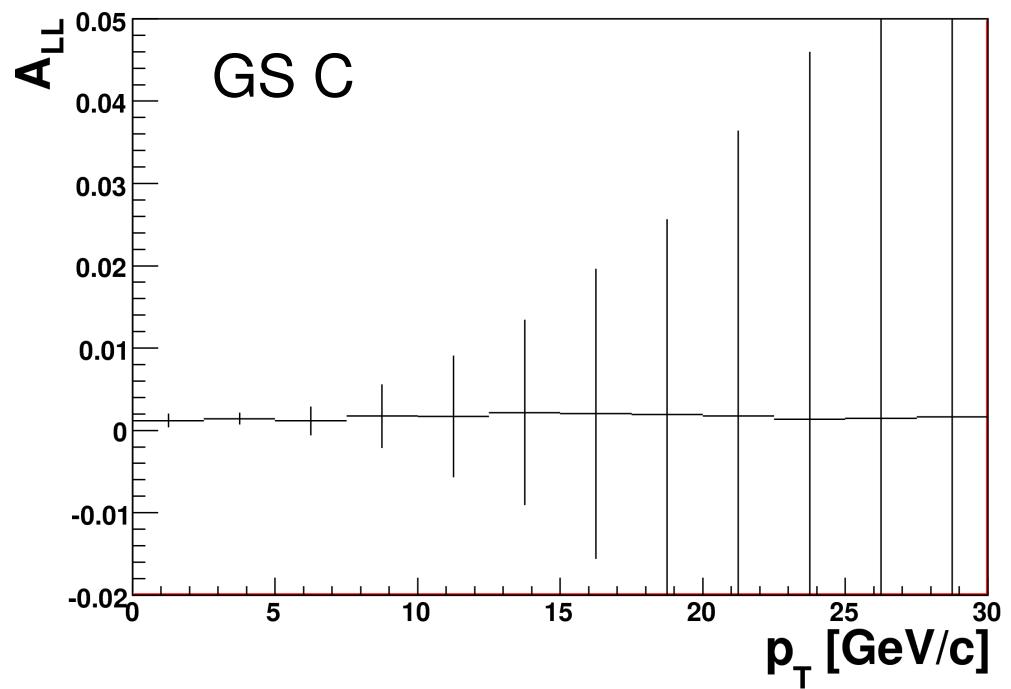
Expected NCC performance

IV. A_{LL} p+p 500 GeV using direct photons



NCC measurement

Both 12 week long run at RHIC II luminosity, 70% polarization



EMC measurement

Summary

Calorimetry at forward rapidity will extend PHENIX's capabilities to explore topics like sQGP, g(x), CGC and proton spin.

New calorimeters like the MPC are already expanding PHENIX's range of rapidity and can be used to study topics like A_N and transversity of partons.

Future calorimeters like the NCC will expand even more of the phase space and provide precision measurements of EM showers including:

- π^0/γ discrimination similar to central arm
- Jet energy and rapidity measurements

Thank You

- Thanks to Mickey Chiu for inviting me to give this talk and providing material and comments on the MPC.
- Thanks to Ondrej Chvala for providing material and comments on the NCC.
- More can be learned about the NCC from Ondrej's talk at:
www.phenix.bnl.gov/WWW/publish/ondrejch/NCC-talk-WWND08-ondrejch.odp
- And thank you for your time and attention.